Fabrication and characterization of Silicon-On-Diamond (SOD) sensors*

S. Sciortino[1,2,#], K. Kanxheri[3,4], S.Lagomarsino[1,2], A. Morozzi[3,4] , G. Parrini[1], D. Passeri[3,4], L. Servoli[4], M. Citroni[5], S. Fanetti[5], E. Berdermann[6], C. J. Schmidt[6], M. Kis[6], M. Träger[6], R. Visinka[6]

[1]Department of Physics, Florence, Italy; [2]INFN, Florence, Italy; [3]University of Perugia, Italy; [4]INFN, Perugia, Italy; [5]LENS, Florence, Italy; 6GSI, Darmstadt, Germany;

We report on the preparation and characterization of integrated diamond detectors implementing the Silicon-On-Diamond (SOD) concept [1]. They have been fabricated by thinning (5×5 mm2) CMOS Monolithic Active Pixel Sensors (MAPS) down to 25 µm and bonding them to polycrystalline Chemical Vapour Deposited (pCVD) diamond plates (5×5×0.5 mm3), by a laser technique [2]. This class of devices exploits the capability of the charges generated in the diamond by ionizing radiation to cross the silicon-diamond interface and to be collected by the MAPS photodiodes. We have assessed that the charge induced in diamond by Minimum Ionizing Particles is collected by the MAPS electronics with an efficiency of about 20 %, depending on the quality of the SOD bonding process and on the silicon-diamond interface. The aim is to prepare low-noise, low material budget integrated radiation hard detectors with a new technique of bonding at the atomic level. Two SOD devices have been implemented (SOD-40 and SOD-43) in this study. The adhesion at the silicon-diamond interface turned out to be better for the SOD-43 device due to technical reasons discussed in [3]. First the CMOS MAPS have been calibrated with monochromatic X-rays, then the device have been tested with charged particles (electrons) either with and without biasing the diamond substrate, to compare the amount of signal collected, We analysed for both SOD prototypes a matrix of 32x32 small photodiode (2x2 μm^2) pixel. The two SOD devices response to X-rays fluorescence has been studied and the calibration relations are very similar. The two calibration factors for the 32x32 small photodiode pixel matrices are: 10.12 ± 0.31 ADC/keV for SOD-40 and 10.43 ± 0.30 ADC/keV for SOD-43. SOD-40 was tested with a ^{90}Sr/Y electron source while SOD-43 was exposed to an electron beam at Beam Test Facility of Frascati, Italy, with beam energy of 345 MeV. The signal collected by the MAPS will have always the component due to the ionization in the silicon layer, while the component due to the diamond should appear only when it is polarized. The carriers created into diamond drift along the applied field toward the silicon-diamond interface and diffuse in the silicon material to be collected by the MAPS. We found that the collected charge remains spatially localized, i.e., almost all the collected charge is inside the 5x5 matrix, centered around the pixel with the maximum signal. By increasing the cluster size we do not add other contributions to the total signal. To evaluate the maximum allowable diamond contribution to the signal we assume that there is no loss in crossing the interface. From a previous work [4] we derive that only a 37% of the charges located at the interface, i.e. at a 25 µm depth in the silicon, will be collected by the MAPS. Assuming a Most Probable Signal (MPS) in the range 7000-8000 e, at 500 V, for the diamond material used for our devices, the maximum signal to be expected from our MAPS is in the interval 2600-3000 e. Figure 1 shows a difference in ADC counts of about 20 for both devices when they are polarized. This amounts to about 540 e injected by diamond, i.e., an efficiency of about 20 % in crossing the silicon-diamond bonding interface. We note that the response due to diamond has an offset voltage of about 250 V which most likely depends on the defective interface. The signal of SOD-43 is higher at 400 V than that of SOD-40. This is tentatively ascribed to the better adhesion between silicon and diamond verified a posteriori in SOD-43, by optical microscopy. We could not verify this hypothesis at higher voltages, due to a high superficial current drawn by the silicon layer.

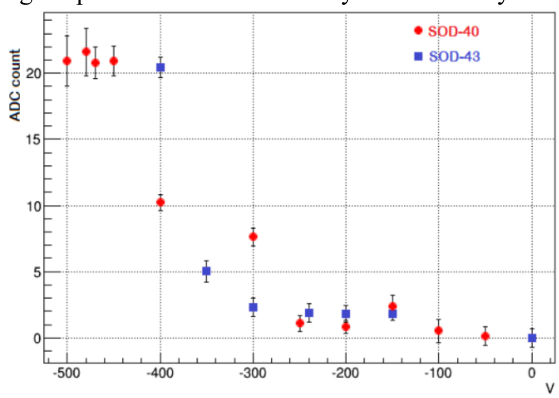

Figure 1: Bias scan for both fully polarized SOD-40 (circles) and not fully polarized SOD-43 in (squares).

References

[1] S. Lagomarsino et al., New perspectives for the Silicon-On-Diamond material, PoS(RD09)029

[2] S Lagomarsino et al., Silicon-on-diamond material by pulsed laser technique, Applied Phys. Lett. 96 (2010) 031901

[3] K. Kanxheri et al., First result on biased CMOS MAPs-on-diamond devices, Nucl. Instr. Meth. A, in press, corrected proofs, 10.1016/j.nima.2015.02.054

[4] S. Meroli, et al. Measurement of charge collection efficiency profiles of CMOS active pixel sensors. Journ. Of Instr. (2012) 07 P09011

* Work supported by EU (HadronPhysics3 project No. 283286) and GSI (Detector Technology and Systems Platform) and INFN Italy (experiment 3D_SOD)

#silvio.sciortino@unifi.it

DOI:10.15120/GR-2015-1-FG-GENERAL-37